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EVALUATION OF THE DCIEM 1983 DECOMPRESSION MODEL FOR COMPRESSED AIR DIVING (SERIES G-K)

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ABSTRACT

The Defence and Civil Institute of Environmental Medicine (DCIEM), Downsview, Ontario, has developed a new mathematical model for decompressing compressed air divers. This model, referred to as the **DCIEM 1983 DECOMPRESSION MODEL**, has been employed for real-time computer-controlled diving using the DCIEM XDC-2 decompression computer. **Standard Air, In-Water Oxygen,** and **Surface Oxygen** decompression procedures have been developed and examined for single and repetitive dives.

The effectiveness of the DCIEM 1983 Decompression Model has been assessed both subjectively (classical symptoms of decompression sickness) and by Doppler ultrasonic bubble detection method.

This report presents the results of 144 single and repetitive dives decompressed with the new model using **In-Water Oxygen** and **Surface Oxygen** decompression. Also presented are the Doppler results of 132 **No-Decompression** (No-D) dives along an "operational" No-D curve proposed for the Canadian Forces which is less conservative than the No-D limit predicted by the model.

This report is a continuation of DCIEM Report No.84-R-72 which presented the results of 391 previous dives decompressed on the DCIEM 1983 Decompression Model (Series A-F).

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INTRODUCTION

This report presents the results of experimental air dives using the DCIEM 1983 Decompression Model and is a continuation of the initial evaluations of that model (1).

In early 1983, DCIEM developed a new model and procedures for decompressing compressed air divers. This model, referred to as the **DCIEM 1983 DECOMPRESSION MODEL** (2) is based on the pioneering decompression work done at DCIEM by Kidd and Stubbs (3,4) and continued by others (5,6).

The culmination of these early efforts was the development of a microprocessor-based digital decompression computer programmed with the Kidd-Stubbs 1971 Decompression Model (KS-1971) - the XDC-2 (7). This instrument has since been used extensively for real-time computer controlled diving at DCIEM (8,9,10). In 1982, XDC-2 controlled Oxygen Decompression procedures were developed and evaluated (11).

DCIEM has been assessing the safety of decompression profiles for compressed air diving with the Doppler ultrasonic bubble detector since 1979. Analyses of a variety of dive data indicate that there is a correlation between the number of bubbles observed in the precordial region and the safety of the decompression procedure. Although Decompression Sickness (DCS) does not necessarily accompany high bubble grades (according to grading schemes such as the Kisman-Masurel (12) or Spencer (13) bubble codes), most of the cases of DCS reported were associated with high bubble grades (grades 3 or 4). Therefore, with decompression profiles which produce high bubble grades, there is a definite risk of DCS, and such profiles should be avoided. Conversely, if decompression profiles consistantly result in no observable bubbles, they may be overly conservative.

The decompression schedules based on the DCIEM 1983 Decompression Model are considerably more conservative than those published in the United States Navy (USN) and the Royal Navy (RN) diving manuals (14,15). However, the initial evaluations of the DCIEM model using Doppler ultrasonic bubble detection methods (1) have proven that this conservatism is justified and necessary. Figure 1 provides a simple comparison of the total decompression times of the DCIEM 1983, USN, and RN Standard Air decompression schedules.

During the initial evaluations (1), **Standard Air, In-Water Oxygen** and a combination of **In-Water Oxygen plus Surface Oxygen** procedures were examined for single dive profiles in the "normal" air diving range

of the limits proposed for the Canadian Forces shown in Figure 2. Several repetitive dive combinations in the normal range were also examined using **Standard Air** and **In-Water Oxygen plus Surface Oxygen** decompression.

This report presents the results of additional evaluations conducted with the DCIEM 1983 Decompression Model. **In-Water Oxygen plus Surface Oxygen** decompression was examined for dive profiles in the "exceptional exposure" range of Figure 2 - to 72 metres of seawater (msw) or 236 feet of seawater (fsw). A more traditional Surface Oxygen (**SurD O_2**) procedure, which uses air only in the water and Oxygen in the Recompression Chamber (RCC) was also examined for single and repetitive dives. Further, the **In-Water Oxygen** method was applied to repetitive dives.

In addition, a series of **No-Decompression (No-D)** dives along a line which is less conservative (for dives to 36 msw) than the **No-D** limit derived from the new model was assessed using Doppler. Figure 3 shows this "operational" **No-D** limit and the "theoretical" **No-D** limit of the DCIEM 1983 Decompression Model. The USN and RN No-D limits are also shown for comparison. Table 1 details all the dive profiles and decompression schedules used for these experiments.

This report presents the general results of these evaluation. A more detailed analysis of the results of these experiments will be published separately.

EXPERIMENTAL METHODS

1. DECOMPRESSION PROCEDURES

The real-time computer-controlled decompression procedures used for these experiments were:

a. **In-Water Oxygen** Decompression

(1) The divers did a normal XDC-2 ascent at 18 msw/min (60 fsw/min) to 9 msw (30 fsw) and stopped;

(2) The divers' gas and the XDC-2 were switched to O_2. The divers remained at 9 msw until the SAD read "0"; and

(3) The divers then surfaced at 4.5 msw/min (Note 1).

b. **In-Water Oxygen + Surface Oxygen** Decompression

(1) The divers did a normal XDC-2 ascent at 18 msw/min to 9 msw and stopped;

(2) The divers' gas and the XDC-2 were switched to O_2. The divers remained at 9 msw until the XDC-2 SAD read "6 msw" (Note 2);

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Note 1: Due to vent rate limitations in the hyperbaric facility used for these experiments, almost 2 minutes were required to surface from 9 msw. Therefore, the decompression profiles presented in Table 1 show a time of 2 minutes for ascent from the 9 msw water stop. (This does not apply to the "No-Decompression" experiments which were conducted in a different facility.)

2: Experience had shown that a diver could be surfaced safely for recompression in a chamber after completing the required 9 msw in-water stop - i.e., when SAD equals 6 msw.

(3) The divers were then brought directly to the surface on O_2, undressed and recompressed to 12 msw (40 fsw) on O_2 in the Recompression Chamber (RCC) as rapidly as possible. The time from leaving the 9 msw water stop to reaching the 12 msw RCC stop, the Surface Interval (SI), was not to exceed 7 minutes (Note 3);

(4) The divers remained at 12 msw breathing O_2 until the XDC-2 SAD read "-1 msw" (Note 4). 5-minute air breaks were taken after every 30 minutes on O_2 (Note 5); and

(5) The divers then surfaced at 6 msw/min on O_2.

c. **Surface Oxygen** Decompression (SurD O_2)

(1) The divers did a normal XDC-2 ascent at 18 msw/min to 9 msw; and

(2) The divers remained on air at 9 msw until the SAD read "6 msw" (Note 6).

(3) The divers were then brought to the surface at 4.5 msw/min, undressed and recompressed to 12 msw in the RCC on O_2. The XDC-2 was switched to "O_2" when the divers started breathing O_2. The SI was not to exceed 7 minutes;

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NOTE 3: The 7-minute SI was chosen to enhance the operability of the procedure and to reduce the chances for "omitted" decompression. The full 7-minute SI was used throughout these experiments.

4: The diver remains on O_2 at 12 msw in the RCC until the indicated SAD = "-1 msw" to provide a compensatory decompression benefit for the time that he was in violation of the model during the SI. By using the computer SAD to define it, this benefit is always proportional to the severity of the dive.

5: The 5-minute air breaks after every 30 minutes on O_2 were introduced to reduce, or eliminate entirely, the possibility of O_2 toxicity problems and for diver comfort. (The XDC-2 is switched to "air" for these air breaks.)

6: To the completion of the 9 msw stop, the decompression is exactly the same as for normal Standard Air decompression.

(4) The divers remained on O_2 at 12 msw with 5-minute air breaks after each 30 minutes on O_2 until the XDC-2 SAD read "-1 msw"; and

(5) The divers then surfaced at 6 msw/min on O_2.

This SurD O_2 procedure is more traditional than the combination of In-Water O_2 + Surface O_2 and lengthens the 9 msw water stop only slightly (i.e., for a 36 msw/50 min dive, the 9 msw stop (on air) is 7 min vs. 4 min on O_2). If, however, minimum water exposures and extended surface intervals are the prime criteria (as may be the case in special military diving scenarios), the combination of In-Water O_2 + Surface O_2 provides an attractive alternative.

Except for the No-D experiments, all dives presented in this report were controlled real-time by the XDC-2 decompression computer.

This paper is a continuation of the DCIEM 1983 Decompression Model validation process and the following is a summation of the experiments previously reported (Series A-F), and those presented in this report - Series G-K:

a.	**Series A**	
	Standard Air Decompression	32 dives
b.	**Series B**	
	Standard Air Decompression	31 dives
c.	**Series C**	
	In-Water O_2 Decompression	93 dives
d.	**Series D**	
	In-Water O_2 + Surface O_2 Decompression	76 dives
e.	**Series E**	
	Standard Air Decompression for selected repetitive dive combinations	62 dive combinations
f.	**Series F**	
	In-Water O_2 + Surface O_2 Decompression for one repetitive dive combination	18 dive combinations

g. **Series G**

In-Water O_2 + Surface O_2 Decompression for selected exceptional exposure profiles	63 dives

h. **Series H**

SurD O_2 Decompression for selected profiles including exceptional exposures	30 dives

i. **Series I**

In-Water O_2 Decompression for one repetitive dive combination	15 dive combinations

j. **Series J**

SurD O_2 Decompression for one repetitive dive combination	11 dive combinations

k. **Series K**

Examination of the proposed **operational No-D limit** which is less conservative than the No-D limit predicted by the DCIEM 1983 Decompression Model.	132 dives

2. DIVE SUBJECTS

Each dive (except for the No-D dives) was planned to include a wet, working diver (on a bicycle ergometer) wearing a Viking dry suit with underwear and a Superlite SL-17B helmet; a wet, swimming diver (swimming against a barrier) and a standby diver wearing Viking dry suits with underwear and AGA Full Face Masks; and two dry, resting subjects and a team leader all wearing coveralls. Heart rates were measured on both wet divers to control the work level as shown in Table 2. For the No-D experiments, all subjects were dry, resting and wearing coveralls. (The No-D dives were conducted in the DCIEM Diver Training Facility which permits ascent rates of 18 msw/min to the surface).

Team leaders were DCIEM Clearance Divers. The other subjects were divers from the DCIEM Ships Diver Roster and the Canadian Underwater Training Centre. The subjects who participated in this study were all male. Their age, weight, and height (means and standard deviations) were 31 $\pm$ 7 yr, 79 $\pm$ 8.2 kg, and 1.74 $\pm$ 0.07 m, respectively.

All dive subjects had a minimum of 36 hours between dives and were asked not to engage in strenuous physical exercise (which was not a part of normal daily routine) for 24 hours pre-dive and for 12 hours post-dive.

3. DOPPLER ULTRASONIC MONITORING PROCEDURES

The instrument used for monitoring bubbles was the model "DUG" Bubble Detector developed by the Institut National des Sciences Appliquées de Lyon for the Centre d'Etudes et de Recherches Techniques Sous-Marines in Toulon, France, and manufactured by Sodelec SA of Marseille, France.

All divers were monitored for bubbles at the precordial site (right ventricle and/or pulmonary artery) and the subclavian sites (both left and right shoulders.) Two conditions were used at each site; in the first condition, the diver stood at rest, and in the second, the diver performed a specific movement. For the precordial site, this movement was a deep knee-bend - squatting and returning to the standing position in a continuous, smooth motion. For the subclavian sites, the movement consisted simply of clenching the fist on the side being monitored.

The Doppler ultrasonic signals, which include contributions from blood flow, cardiac motion, and bubbles, were simultaneously recorded on audio magnetic tape and assessed aurally. In cases of doubt, the tape recording was replayed and compared with the pre-dive reference recording. The bubble signals were classified according to the Kisman-Masurel code (12) which uses three criteria (each on a scale from 0 to 4):

a. the number of bubbles per cardiac cycle;

b. the percentage of cardiac cycles with bubbles; and

c. the amplitude of the bubble signals relative to the background.

The resulting 3-digit code was used to obtain a global bubble grade from 0 to 4. This bubble grade scale is similar to the other commonly used bubble grade scale developed by Spencer (13).

Monitoring was performed by two teams of experienced technicians. The reference signal was recorded before each dive, and each subject was monitored at half-hour intervals for at least 2 hours following the end of decompression. During this time, the divers were asked to rest in the immediate vicinity, and to refrain from excessive post-dive activity, since this is thought to contribute to decompression problems

(8). If bubbles were detected, the subject was required to remain under observation until the bubbles diminished to insignificant numbers. For the repetitive diving experiments, the subjects were monitored between dives as well as after the second dive.

The subjects were asked to report any pain or other symptoms of decompression sickness (DCS). The attending Diving Medical Officer considered subjective symptoms only, not bubble grades, in deciding whether to treat for DCS.

4. ANALYSIS PROCEDURES

The Doppler results, expressed as bubble grades, were used to assess the decompressions stress experienced by each subject for a given dive profile and decompression method. A high bubble grade was considered indicative of a stressful dive for that individual. If several of the divers had high bubble grades, then this pointed to a stressful profile. These results were qualitative.

As previously stated, a much more detailed analysis of the results of these experiments will be published separately.

RESULTS

1. DIVE PROFILES

The left half of Table 3 presents the actual dives carried out with the total number of subjects in each dive and the number of wet, working divers. The water temperature for wet divers was 10.°C. (Not all subjects were allowed to dive for medical or other reasons on their designated dives, and this accounts for the variation in the number of subjects in each dive.)

A total of 63 man-dives in the exceptional exposure range of the proposed air diving limits shown in Figure 2 were decompressed with the In-Water O_2 + Surface O_2 method and are reported as Series G. Series H consisted of 30 man-dives (including 21 exceptional exposures) decompressed with the new SurD O_2.

Series I consisted of 15 repetitive man-dive combinations using In-Water O_2 decompression. Series J repeated the same repetitive dive profiles with the new SurD O_2 method for 11 man-dive combinations.

Series K consisted of 132 No-D man-dives along the "operational" No-D limit proposed for the Canadian Forces.

2. DOPPLER RESULTS

The right half of Table 3 summarizes the peak bubble grades observed for all dives grouped by dive profiles and decompression methods. A bubble grade of "0" represents no detectable bubbles. Increasing bubble grades indicate increasinly larger numbers of bubbles, with grade "1" representing only 1 or 2 bubbles per cardiac cycle, and grade "4" representing bubbles too numerous to count.

Tables 4 and 5 provide the detailed Doppler results for selected dive profiles using different decompression methods.

Table 6 presents a summary of the percentage of man-dives decompressed with the DCIEM 1983 model (including dives from Series B-F and Series G-J) which resulted in no detectable bubbles, or only 1 or 2 bubbles per cardiac cycle (Doppler scores of "0" or "1").

Only one man-dive out of 132 No-D dives resulted in detectable bubbles in the precordial region. This was a 18 msw/50 min dive which resulted in a Doppler score of 0/1 (at rest/after movement).

3. DECOMPRESSION SICKNESS (DCS)

The number of incidents of DCS on each profile are shown in Table 3 (last column). All cases of DCS were treated using USN Treatment Tables (14).

a. In-Water O_2 + Surface O_2 Decompression - Series G

Four incidents of DCS occurred in 63 exceptional exposure man-dives using the In-Water O_2 + Surface O_2 decompression method.

(1) Subject JPE experienced slight pain in both knees and the left shoulder 20 minutes after a 54 msw/45 min dive. His precordial Doppler score was 3/3 at this time. He was treated for Type I DCS on Table 5, and full relief was attained on descent to 60 fsw;

(2) Subject MD experienced a slight pain in the right elbow during the surface interval following a dive to 72 msw for 40 min as wet, working diver. This pain disappeared on recompression to the 12 msw RCC stop but recurred on completion of the decompression. He was not monitored and was treated immediately for Type I DCS on Table 6 and total relief was attained on descent to 60 fsw. He reported feeling tired prior to the dive.

(3) Subject GSP experienced pain in his left knee upon surfacing after a dive to 72 msw for 40 min as a dry, resting subject. He was not monitored and was treated for Type I DCS on Table 5 with total relief at 7 fsw on descent. He reported not having slept well for several days prior to this incident.

(4) Subject RSW was a dry, resting diver for a dive to 72 msw for 40 minutes, and his Doppler score was minimal (0/1 in right shoulder). He developed a "backache" approximately 14 hrs post-dive but did not report this until the following morning when he also experienced numbness in both legs. He was treated for Type II DCS on Table 6, 24 hrs post-dive and reported marginal relief after 16 minutes at 60 fsw. Follow-up treatment was conducted at Toronto General Hospital (5 x Table 5). After this extensive treatment, the subject still complained of "intermittent, burning numbness" in his back. RSW was reported to have participated in a wrestling match during a party prior to the onset of the back pain.

b. **SurD O_2 Decompression - Series H**

No incidents of DCS occurred in 30 man-dives (including 21 exceptional exposures) using the new SurD O_2 method;

c. **In-Water O_2 Decompression - Repetitive Dives - Series I**

One incident of DCS occured in 15 man-dive combinations.

Subject JL was the wet, swimming diver for the repetitive dive combination (45 msw/30 min plus 45 msw/20 min with a 2 hr Surface Interval). Fifteen minutes after surfacing from the first dive, JL reported pain in his right shoulder. His Doppler score was 2/2 in the right shoulder as well as in the precordial region. He was treated for Type I DCS on Table 5 and had complete relief on descent at 22 fsw;

d. **SurD O_2 Decompression - Repetitive Dives - Series J**

No incidents of DCS occurred in 11 man-dive combinations; and

e. **No Decompression - Series K**

No incidents of DCS occurred in 132 No-Decompression dives.

DISCUSSION

Subjectively, five confirmed or probable incidents of DCS occurred in 144 man-dives which were decompressed with the DCIEM 1983 Decompression Model. This is an overall incidence of DCS of 3.5% and correlates well with the 3.3% incidence rate observed in the 391 man-dives conducted during Series A-F (1).

Out of the five cases of DCS, two were not Doppler-monitored prior to treatment (subjects MD and GSP after 72 msw/40 min dive), and one resulted in a minimal Doppler score (subject RSW, 72 msw/40 min). The remaining two incidents resulted in 2/2 and 3/3 peak scores. All victims, except subject RSW (who was not treated until 24 hours post-dive), reported total relief of symptoms on descent to the treatment depth (60 fsw).

The more traditional **SurD O_2** method (using air only in the water) examined in Series H and J appears to result in slightly higher Doppler scores than the In-Water O_2 + Surface O_2 procedure examined in Series G. However, the **SurD O_2** method resulted in no incidents of DCS in 41 man-dives (including 21 exceptional exposures), while the In-Water O_2 + Surface O_2 procedure resulted in a 5% incidence rate of DCS (seven cases in 139 man-dives in Series D, F, and G).

The application of **In-Water O_2** decompression to **repetitive diving** appears to be effective and is more "time-efficient" than the **Standard Air** and **SurD O_2** procedures.

The **No-D** dives conducted in Series K resulted in minimal Doppler scores, as expected. No incidents of DCS occurred in 132 man-dives along the proposed "operational" No-D curve. Based on these results and previous No-D experiments (10), the proposed No-D limit is considered a safe compromise between the conservative limit defined by the DCIEM 1983 model and USN No-D limit.

In summary, it can be stated that the results of all the evaluation dives performed to date (Series A-K) tend to confirm that the conservatism of the DCIEM 1983 Decompression Model is justified and necessary. Further, the application of **In-Water O_2** and **SurD O_2** decompression procedures to **repetitive diving** have been shown to be effective and safe.

Additional Doppler-monitored experimental dives will be conducted at DCIEM with this new model in order to increase the Doppler data base. Decompression tables and procedures for compressed air diving based on the DCIEM 1983 Decompression Model will be published in the near future.

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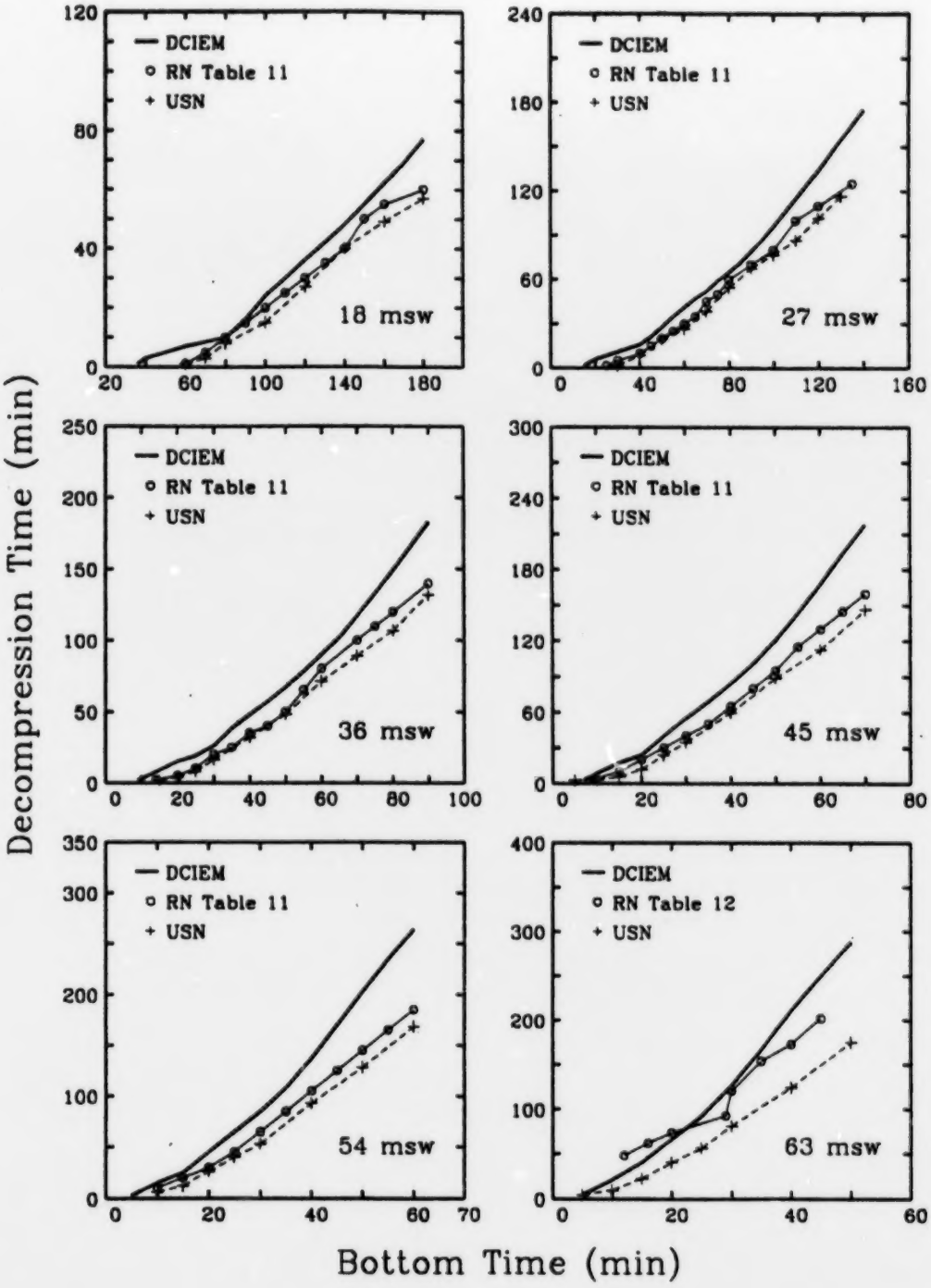

FIGURE 1

COMPARISON OF THE DCIEM 1983 DECOMPRESSION TIMES FOR "STANDARD AIR" DECOMPRESSION WITH THOSE OF THE US NAVY STANDARD AIR TABLE AND ROYAL NAVY TABLES 11-12.

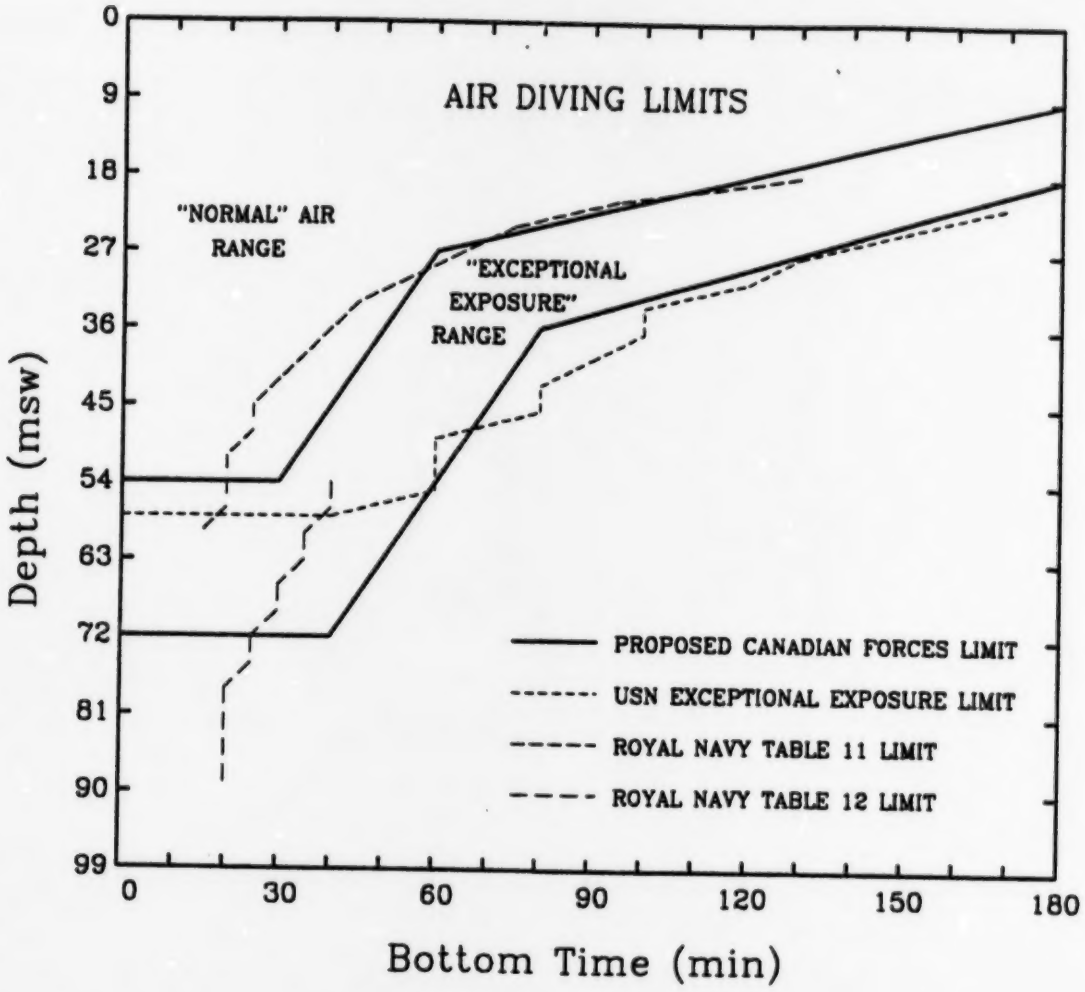

FIGURE 2

PROPOSED AIR DIVING LIMITS FOR THE CANADIAN FORCES

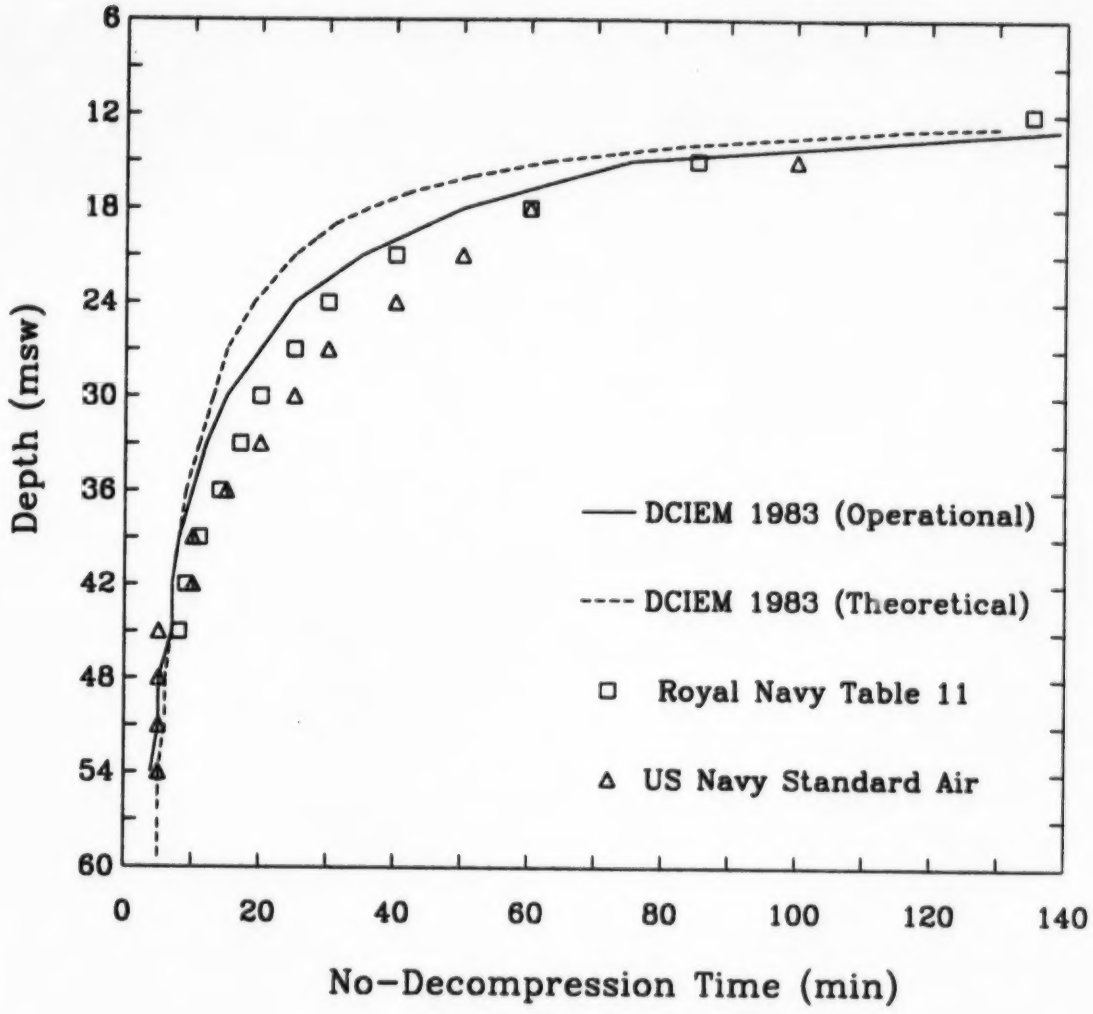

FIGURE 3

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TABLE 1

DECOMPRESSION PROFILES TESTED

SERIES G. IN-WATER O_2 + SURFACE O_2 DECOMPRESSION

Depth (msw)	Bottom Time (min)	Stop times (min) at Different Depths (msw)													Decom Time• (min)
		In-water Stops								Surface			Chamber		
		Air							O_2	O_2	Air	O_2	O_2		
		30	27	24	21	18	15	12	9	Asc	SI	Des	12	Asc	
36	60	-	-	-	-	-	-	6	4	2	4	1	49	2	73
54	45	-	-	-	4	4	5	7	10	2	4	1	70	2	119
63	30	-	-	-	5	4	4	7	5	2	4	1	58	2	97
45	70	-	-	-	-	5	5	8	14	2	4	1	85	2	136
72	40	3	3	3	4	6	6	13	19	2	4	1	103	2	184

SERIES H. SURFACE O_2 DECOMPRESSION (Sur D O_2)

Depth (msw)	Bottom Time (min)	Stop times (min) at Different Depths (msw)													Decom Time• (min)
		In-water Stops								Surface			Chamber		
		Air								Air		O_2	O_2		
		30	27	24	21	18	15	12	9	Asc	SI	Des	12	Asc	
36	50	-	-	-	-	-	-	4	7	2	4	1	42	2	67
54	30	-	-	-	-	3	4	6	7	2	4	1	47	2	81
63	30	-	-	-	5	4	4	7	8	2	4	1	60	2	107
72	40	3	3	3	4	6	6	13	28	2	4	1	114	2	204

SERIES I. REPETITIVE IN-WATER O_2 DECOMPRESSION

Prof.	Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)					Decom. Time (min)
			Air			O_2		
			18	15	12	9	Asc	
2	45	30	-	-	6	30	2	38
	45	20(30)†	-	-	-	32	2	34

SERIES J. REPETITIVE SURFACE O_2 DECOMPRESSION (Repet Sur D O_2)

Prof.	Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)									Decom. Time• (min)
			In-Water Stops				Surface			Chamber		
			Air				Air		O_2	O_2		
			18	15	12	9	Asc	SI	Des	12	Asc	
2	45	30	-	-	6	6	2	4	1	30	2	56
	45	20(32)†	-	-	-	8	2	4	1	36	2	58

• Decompression time includes 5 min air breaks after every 30 min on O_2 in the chamber.
† Times shown in () are Effective Bottom Times for second dives

TABLE 1 (continued)

DECOMPRESSION PROFILES TESTED

SERIES K. NO DECOMPRESSION PROFILES

Depth (msw)	Bottom Time (min)	Depth (msw)	Bottom Time (min)
15	75	36	10
18	50	39	8
21	35	42	7
24	25	45	7
27	20	48	6
30	15	51	5
33	12	54	5

TABLE 2

WORKLOAD FOR WET DIVERS

Bottom Time (min)	Workload	Percentage of Max. Heart Rate At Surface	Work/Rest Cycle
over 60 min	1	50%	Continuous
31 to 60 min	2	65%	10 min/10 min
21 to 30 min	3	70%	5 min/ 5 min
10 to 20 min	4	75%	3 min/ 2 min

TABLE 3 (continued)

MAXIMUM BUBBLE GRADES OBSERVED IN THE PRECORDIAL REGION AT REST AND FOLLOWING MOVEMENT FOR ALL DIVES

SERIES K. NO-DECOMPRESSION DIVES

Depth (msw)	Bottom Time (min)	No. of Subj.	No. Man Dives	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
15	75	8	8	8	0	0	0	0	8	0	0	0	0	0
18	50	11	11	11	0	0	0	0	10	1	0	0	0	0
21	35	10	10	10	0	0	0	0	10	0	0	0	0	0
24	25	11	11	11	0	0	0	0	11	0	0	0	0	0
27	20	11	11	11	0	0	0	0	11	0	0	0	0	0
30	15	10	10	10	0	0	0	0	10	0	0	0	0	0
33	12	12	12	12	0	0	0	0	12	0	0	0	0	0
36	10	11	11	11	0	0	0	0	11	0	0	0	0	0
39	8	8	9	9	0	0	0	0	9	0	0	0	0	0
42	7	16	17	17	0	0	0	0	17	0	0	0	0	0
45	7	6	6	6	0	0	0	0	6	0	0	0	0	0
48	6	7	7	7	0	0	0	0	7	0	0	0	0	0
51	5	4	4	4	0	0	0	0	4	0	0	0	0	0
54	5	5	5	5	0	0	0	0	5	0	0	0	0	0
TOTALS			84	84	0	0	0	0	83	1	0	0	0	0

TABLE 3

MAXIMUM BUBBLE GRADES OBSERVED IN THE PRECORDIAL REGION AT REST AND FOLLOWING MOVEMENT FOR ALL DIVES

SERIES G. IN-WATER O_2 + SURFACE O_2 DECOMPRESSION

Depth (msw)	Bottom Time (min)	No. of Subj.	No. Man Dives†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
36	60	10	10(4)	7	0	3	0	0	6	1	0	2	1	0
54	45	8	11(4)	7	2	1	2	0	7	2	0	2	0	1
63	30	12	12(4)	5	2	4	1	0	5	1	1	5	0	0
45	70	10	13(4)	6	2	2	3	0	5	2	1	5	0	0
72	40	17	17(4)	10	2	2	1	0	12	0	0	3	0	3*
TOTALS			63(20)	35	8	12	6	0	35	6	2	17	1	4

* Two subjects with DCS not monitored

SERIES H. SURFACE O_2 DECOMPRESSION (Sur D O_2)

Depth (msw)	Bottom Time (min)	No. of Subj.	No. Man Dives†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
36	50	5	5(2)	2	1	2	0	0	2	0	1	2	0	0
54	30	4	4(2)	3	0	0	1	0	3	0	0	1	0	0
63	30	11	11(4)	6	0	1	4	0	6	0	0	5	0	0
72	40	10	10(4)	2	1	2	5	0	2	1	0	6	1	0
TOTALS			30(12)	13	2	5	10	0	13	1	1	14	1	0

SERIES I. REPETITIVE IN-WATER O_2 DECOMPRESSION

Depth (msw)	Bottom Time (min)	No. of Subj.	No. Man Dives†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
45	30	13	15(6)	8	2	2	3	0	8	0	3	4	0	1**
45	20(30)‡	13	14(5)	10	2	0	2	0	10	1	1	2	0	0
TOTALS			19(11)	18	4	2	5	0	18	1	4	6	0	1

** Subject with DCS did not dive second dive

SERIES J. REPETITIVE SURFACE O_2 DECOMPRESSION (Repet Sur D O_2)

Depth (msw)	Bottom Time (min)	No. of Subj.	No. Man Dives†	Man-Dives with Maximum Bubble Grade										No. of DCS
				At Rest					After Movement					
				0	1	2	3	4	0	1	2	3	4	
45	30	11	11(4)	8	2	0	1	0	6	0	3	2	0	0
45	20(32)‡	11	11(4)	11	0	0	0	0	11	0	0	0	0	0
TOTALS			22(8)	19	2	0	1	0	17	0	3	2	0	0

† Numbers in () indicate number of wet divers

‡ Times shown in () are Effective Bottom Times for second dives

TABLE 4

COMPARISON OF OLD AND NEW SURFACE OXYGEN DECOMPRESSION METHODS
MAXIMUM BUBBLE GRADES FROM THE PRECORDIAL AND SUBCLAVIAN SITES

SERIES G. IN-WATER O_2 + SURFACE O_2 DECOMPRESSION

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
63/30	BB	DR	0	-	0	-	0	-	
	MC	WW	1/2	158	0	-	0	-	
	MD	WW	0	-	0	-	0	-	
	MF	DR	2/3	204	0	-	0	-	
	SN	L	2/3	167	0	-	0	-	
	LT	S	0	-	1/1	198	0	-	
	TNB	WW	0	-	0	-	2/3	107	
	KP	DR	1/1	204	0	-	0	-	
	AR	L	0	-	0	-	0	-	
	AS	S	2/3	232	0	-	0	-	
	MT	DR	2/3	115	0	-	3/2	115	
	RSW	WW	3/3	144	0	-	0	-	

SERIES H. SURFACE O_2 DECOMPRESSION (Sur D O_2)

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
63/30	FBC	WW	3/3+	105	1/1	138	3/3-	105	
	PD	DR	0	-	0	-	0	-	
	BM	TL	3-/3-	179	2/2	179	2/3-	179	
	MN	S	2/3-	199	3-/1	199	3/2+	199	
	DS	WW	0	-	0	-	0	-	
	DB	S	0	-	0	-	0	-	
	RF	WW	0	-	0	-	0	-	
	BG	DR	3-/3	181	0	-	0	-	
	LH	TL	0	-	0/1-	212	0/1	140	
	JL	DR	3/3+	285	0	-	1/2-	199	
	LN	WW	0	-	3-/2	168	0/1	105	

TABLE 5

COMPARISON OF REPETITIVE DIVE PROFILES WITH DIFFERENT METHODS
MAXIMUM BUBBLE GRADES FROM THE PRECORDIAL AND SUBCLAVIAN SITES

SERIES E - REPETITIVE STANDARD AIR DECOMPRESSION

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
45/30+45/20 2 hr SI	TNB	DR	0	-	0	-	3/2	107	
		DR	0	-	0	-	2/2	137	
	TNB	WW	0	-	1/1	83	3/2	83	
		WW	0/1	50	0	-	3/3	50	Type1
	RF	DR	0/1	140	2/1	99	2/2	99	
		DR	0	-	0/1	83	1/1	83	
	RF	DR	0/1	79	0/1	131	2/1	179	
		DR	0	-	1/1	76	3/2	105	
	IK	WW	1/2	118	1/1	118	0	-	
		WW	0	-	0	-	1/1	98	
	IK	DR	0	-	0	-	0	-	
		DR	0	-	0	-	0	-	
	SP	WW	1/2	123	0	-	0	-	
		WW	2/3	117	0	-	1/0	117	
	SP	DR	0/1	100	0	-	0	-	
		DR	0	-	0	-	0	-	
	GSP	DR	3/3	129	2/3	84	1/2	129	
		DR	3/3	92	NM	-	NM	-	Type 1
	DRP	DR	0	-	0	-	0	-	
		DR	0	-	0/1	89	0	-	
	DRP	DR	0	-	0	-	0	-	
		DR	0	-	0	-	0	-	
	KP	DR	0	-	0	-	0	-	
		DR	0	-	0	-	0	-	
	KP	DR	0	-	0	-	0	-	
		DR	0	-	0	-	0	-	
	MT	DR	3/3	133	0	-	1/1	133	
		DR	0	-	1/1	204	3/3	112	
	MT	WW	3/3	124	3/3	124	3/2	124	
		•							
	RSW	DR	0/1	100	0	-	2/1	100	
		DR	0	-	0	-	0/1	98	
	RSW	DR	0	-	0	-	0	-	
		DR	0	-	0	-	0	-	
	SMD	L	0	-	0	-	0	-	
		L	0	-	0	-	0	-	
	SS	S	3/3	137	0	-	3/3	92	
		S	3/3	124	0	-	3/2	124	
	AR	L	0	-	0	-	0	-	
		L	0	-	0	-	0	-	
	AS	S	0/1	72	0	-	3/3	112	
		S	0	-	0	-	0	-	

TABLE 5 (continued)

COMPARISON OF REPETITIVE DIVE PROFILES WITH DIFFERENT METHODS
MAXIMUM BUBBLE GRADES FROM THE PRECORDIAL AND SUBCLAVIAN SITES

SERIES I. REPETITIVE IN-WATER O_2 DECOMPRESSION

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
45/30+45/20	GF	S	3-/3	112	0	-	1/1	112	
2 hr SI			1/2	166	0	-	1/1	50	
	BG	WW	3/3+	97	2/2	97	0	-	
			3/3	53	0	-	1/1	53	
	BH	TL	0	-	0	-	0	-	
			0	-	0	-	0	-	
	JL	WW	2/2	89	0/1	89	2/2	51	Type 1
		•							
	FBC	WW	1/2	112	0	-	0	-	
			0	-	0	-	0	-	
	PD	WW	0	-	0	-	0	-	
			0	-	0	-	0	-	
	DS	DR	0	-	0	-	0	-	
			0	-	0	-	0	-	
	SS	S	0	-	0	-	0	-	
			0	-	0	-	0	-	
	LT	TL	0	-	0	-	0	-	
			0	-	0	-	0	-	
	RF	WW	1/2	52	1/1	52	0	-	
			3-/3-	81	1/1	126	2/2	81	
	BG	DR	3-/3-	95	0	-	0	-	
			0	-	0	-	0	-	
	JL	DR	0	-	0	-	0	-	
			0	-	0	-	0	-	
	MN	S	0	-	0	-	0/2	101	
			1/1	97	0	-	3/2-	133	
	LN	WW	0	-	0/2	105	3-/2	80	
			0	-	1/1	117	1/1	75	
	SN	TL	2/3-	95	0	-	0	-	
			0	-	0	-	0	-	

• did not dive second dive

TABLE 5 (continued)

COMPARISON OF REPETITIVE DIVE PROFILES WITH DIFFERENT METHODS
MAXIMUM BUBBLE GRADES FROM THE PRECORDIAL AND SUBCLAVIAN SITES

SERIES J. REPETITIVE SURFACE O_2 DECOMPRESSION (Repet Sur D O_2)

DIVE (msw/min)	DIVER	ROLE	P	T (min)	LS	T (min)	RS	T (min)	DCS
45/30+45/20 2 hr SI	FBC	DR	0	-	0	-	0	-	
			0	-	0	-	0	-	
	AD	S	0	-	3-/2	20	1/1	104	
			0	-	0	-	0	-	
	PD	WW	0	-	0	-	0/2	136	
			0	-	0	-	0	-	
	GF	TL	1/2	98	0	-	0	-	
			0	-	0	-	0	-	
	DS	WW	1/2	97	0	-	0	-	
			0	-	0	-	0	-	
	RF	DR	0	-	0	-	1/1	143	
			0	-	0	-	0	-	
	BG	WW	0/2	131	0	-	0	-	
			0	-	0	-	0	-	
	JL	WW	3-/3-	132	0	-	0	-	
			0	-	0	-	0	-	
	LN	DR	0	-	1/1	138	1/1	138	
			0	-	0/1	77	1/0	108	
	SN	S	0/3-	114	0	-	0	-	
			0	-	0	-	0	-	
	LT	TL	0	-	0	-	0	-	
			0	-	0	-	0	-	

TABLE 6

COMPARISON OF MAN-DIVES USING THE DCIEM 1983 DECOMPRESSION MODEL WHICH RESULTED IN "MINIMAL" DOPPLER SCORES (GRADES "0" OR "1", PRECORDIAL, AFTER MOVEMENT)

Profile (msw/min)	Percentage of Man-Dives Decompression Method			
	Standard Air	In-Water O_2	In-Water O_2 + Surface O_2	Sur D O_2
27/60	-	83(23C)†	89(19D)	-
36/50	18(11B)	42(24C)	62(21D)	40(5H)
36/60	-	-	70(10G)	-
45/30	58(31B,E•)	53(15I•)	94(18F•)	55(11J•)
45/40	-	86(22C)	86(22D)	-
45/70	-	-	54(13G)	-
54/30	71(21E•)	79(24C)	79(14D)	75(4H)
54/45	-	-	82(11G)	-
63/30	-	-	50(12G)	55(11H)
72/40	-	-	71(17G)	30(10H)
45/30+45/20••	85(20E)	73(15I)	100(18F)	100(11J)

• Includes first dives of repetitive dives

•• After second dive of repetitive dives

† Figures and letters in () are number of man-dives and dive series